ELSEVIER

Aquaculture 205 (2002) 203–219

Aquaculture

www.elsevier.com/locate/aqua-online

The benefits and risks of aquacultural production for the aquarium trade

Michael Tlusty *

Edgerton Research Laboratory, New England Aquarium, Central Wharf, Boston, MA 02110, USA

Received 15 February 2001; accepted 2 May 2001

Abstract

Production of animals for the aquarium hobbyist trade is a rapidly growing sector of the aquacultural industry, and it will continue to become more important as restrictions are placed on collecting animals for the wild. Currently, approximately 90% of freshwater fish traded in the hobbyist industry are captively cultured. However, for marine ornamentals, the reverse is true as only a handful of species is produced via aquaculture technology. Given the future importance of aquaculture production of ornamental species, it is important to elucidate the benefits and risks for this sector. Thus, here the production of ornamental species is compared to the production of food species. The most notable difference is that the marine coastal environment is not currently utilized in the production of ornamental species. Thus, public opposition will not be as great since there is no direct impact on the marine environment. In assessing the benefits and risks of ornamental aquaculture production, the cases where further development should and should not be pursued are developed. In general, aquaculture production of ornamental species should be pursued when species are difficult to obtain from the wild, breeding supports a conservation program, there is some environmental benefit or elimination of environmental damage via the breeding program, or to enhance the further production of domesticated species. Aquaculture production of ornamental species should be avoided when it would replace a harvest of wild animals that maintains habitat, a cultural benefit, or an economic benefit.

Keywords: Ornamental fish aquaculture; Tropical fish; Aquarium trade

1. Introduction

Aquaculture is generally considered to be the rearing or husbandry of aquatic organisms for commercial purposes (Landau, 1992). It is differentiated from capture fisheries in that

* Tel.: +1-617-973-6715; fax: +1-617-723-6207.
E-mail address: mtlusty@neaq.org (M. Tlusty).

0044-8486/02/$ - see front matter
PII: S0044-8486(01)00683-4

there is ownership of the stock, and there is deliberate human intervention at some point in the production cycle (Naylor et al., 2000). While a majority of aquacultural production worldwide is devoted to food production, ornamental fish production is an important component of the aquaculture industry in several nations. In Singapore, ornamental fish accounts for 40% of their total exports (Tay, 1977; L. Chuan, Agri-food and Veterinary Authority of Singapore, pers. comm.). In the United States, ornamental fish production is the fourth largest sector behind catfish, trout, and salmon. Even though it is a prominent sector, it accounts for only 7% of total US aquacultural production (JSA, 1999). The interest in production of ornamental fish is evident in that US production more than doubled between 1985 and 1997, with Florida producing approximately 80% of the total value (FASS, 1999).

Most of the aquacultural production of ornamental fish focuses on freshwater species. Approximately 90% of freshwater ornamental fish are captively bred (Dawes, 1998). In the US, farms in Florida produce 800 varieties of freshwater fish (FL Seafood, 2000), with an estimated price per pound of US$35 to $60 (Hoff, 1996). While marine ornamentals capture a much higher price per pound (estimated US$400 to $600, Hoff, 1996), their captive breeding and culture is much less advanced (Dawes, 1998). Only 100 of 800 marine species traded in the pet industry are routinely bred in captivity (Dawes, 1998), with approximately 21 of these being commercially feasible (Schiemer, 2001).

There is continued interest in developing methods for new freshwater species as well as advancing the culture of marine species. Culture of ornamental fish and invertebrates is now recognized as a feasible alternative to a wild harvest of specimens. Many collecting localities currently limit either the number of fish or the number of species taken, or both. The Bahamian government has a limit of 50 individuals per permitted species (D. Laughlin, New England Aquarium, pers. comm.), the Florida Keys has imposed size restrictions on 49 species of fish (D. Laughlin, pers. comm.), while Brazil allows only 180 species to be exported (Chao and Prang, 1997). A long history of destructive collecting practices, combined with poor husbandry after collection, has damaged the long-term health of reefs with subsequent negative impacts on the potential for harvesting animals and the associated economic benefits of this harvest (Baquero, 1999). Cultivation can help sustain the ornamental fish industry, restore exploited and impacted wild populations, and minimize future use conflicts (HBOI, 2000). In addition, mounting pressure from conservation groups and governments will restrict collection of wild organisms which leaves aquaculture as the only means to satisfy market demand for these products.

With the rapid growth of aquacultural production of ornamental fish, an a priori analysis of benefits and risks of the industry is necessary. Ecological and social implications of aquaculture are not always straightforward. Food fish aquaculture was practiced as early as 2500 B.C. (Landau, 1992), yet the benefits and risks are still being debated (New, 1996, Pillay, 1996; Goldburg and Trippet, 1997; Kautsky et al., 1997; Naylor et al., 2000). This discussion has ensued in part because aquaculture encompasses a diverse array of production scenarios, yet emphasis (particularly criticism) is generally focused on intensive systems in coastal areas, e.g. marine shrimp and salmon farming (Edwards, 1997). Elucidating the position of ornamental fish production in the overall aquaculture scheme will assist in determining where further development would be most beneficial, and where it should be developed cautiously.

In this paper, food production aquaculture is briefly reviewed, and compared to the production of species for the aquarium trade. A majority of the discussion focuses on ornamental fish since that is where most of the industry's effort is placed. However, the ideas put forth are applicable across taxa. Aquacultural production of ornamental species differs slightly from food production. Given a growing interest in aquacultural production for the aquarium trade, it is instructive to compare these two types of production systems, and to catalog the benefits and risks of ornamental aquaculture. Analyses of the benefits and risks of ornamental aquaculture determine those cases in which further development is appropriate. This analysis also develops criteria to assess whether development for ornamental species should either be cautiously approached, or avoided all together.

2. Benefits and risks of food fish aquaculture

The current benefit and risk analysis of the aquaculture industry focuses on the food production sector. Only a brief overview is given here since numerous review articles have been written, and the benefits and risks are still being widely debated. In general, the benefits of this type of aquaculture include increased global production of food, lessened impacts on wild stocks, more efficient production, and economic support of smaller coastal communities (Landau, 1992; New, 1996; Olsen, 1996; Pillay, 1996). Benefits that are less discussed include, species conservation (Munford and Baxter, 1991; Anonymous, 2000), and research into life history characteristics particularly of the early stages (Nicosia and Lavalli, 1999). The risks of food fish aquaculture include nutrification of water bodies, addition of anti-biotics and other chemicals to the ecosystem, introduction of non-native species, user conflicts, and impacts to predators as well as smaller fish used as fish meal used for diet formulation (Raa and Liltved, 1991; Goldburg and Trippet, 1997; Kautsky et al., 1997; Naylor et al., 2000).

Aquacultural production scenarios range from intensive systems where all food is provided, to extensive aquaculture where predators and competitors are controlled. The exact benefits and risks are specific to the type of production system and the species being cultured (Edwards, 1997, see Table 1). For example, nutrification is of concern to intensive production, such as salmon (*Salmo* and *Oncorhynchus* species) aquaculture (Gowen and Bradbury, 1987; Wallin, 1991; Ervik et al., 1997; Tlusty et al., 1999). However, shellfish production cleanses the water of nutrients (Newell, 1988; Rice et al., 2000). Other production systems utilize animal and human waste products as food or fertilizer (Landau, 1992; Tacon, 1995; Pillay, 1996), thus reducing total environmental loading. Similarly, farming carnivorous species (e.g. salmon, tuna, shrimp) has a much smaller positive impact in world food supplies than does farming omnivorous or herbivorous species such as tilapia or carp (Tacon, 1995; Naylor et al., 2000). This diverse nature of aquaculture leads to the paradox that it is often proposed as a solution to global food supply issues, but may actually be a net consumer of fish and reduce the availability of fish for people (Naylor et al., 2000).

Table 1
Benefits and risks of food production aquaculture

Benefits	Comments
Increase global food production	largest increase for herbivorous species
Decrease impacts on wild stocks	aquaculture tends to account for additional fish consumption, as wild harvests have not declined
Increase efficiency	tends to centralize operations, biggest gains in intensive operations
Economic support of smaller communities	especially for marine coastal aquaculture
Species conservation	beginning to be important for salmon
Research	necessary to further address efficiency, water quality, etc., benefits all production scenarios
Risks	**Comments**
Nutrification of water bodies	most prevalent in intensive systems
Use of chemical therapeutents	most prevalent in intensive systems
Introductions of nonnative species	most prevalent in intensive and coastal aquaculture
User conflicts	greatest in developed areas, and in marine settings
Impacts to Predators	greatest in open systems
Increased use of fish meal	most prevalent with carnivorous species.

A similar duality is observed when discussing the impact on wild stocks (Bartley and Casal, 1998). Aquacultural production can have many positive impacts on wild species. Much of the development of technology now used in food production systems was actually developed as part of enhancement programs (Landau, 1992). Currently, enhancement programs benefit over 65 marine or brackish water species with Japan researching an additional 60 species (Bartley, 1999). In addition, aquacultural production of food-fish reduces the number of wild animals that need to be caught for food. However, there is a fear that escapees from aquacultural operations may pose a serious biological threat to wild stocks of native species through competition for resources, genetic dilution of the native stock, and changes in habitat and fauna. (Bartley and Casal, 1998). There are a few cases to support these fears (Hutchinson, 1997; Bartley and Casal, 1998). These examples point to the fact that in debates regarding aquaculture, the type of production system being discussed must first be specified, and that impact can be specific to a certain production scenario. There is also a need to use current information in debates regarding aquaculture (Fossbakk, 2000). With these caveats, I now define the ornamental aquacultural industry and compare it to food production aquaculture.

3. Comparison of ornamental and food aquaculture

Ornamental fish aquaculture is conducted in completely closed tank culture, in ponds, or in cages in ponds (Tamaru et al., 1997). In Florida, the ponds are water-table ponds in sandy loam or coral bedrock (Watson and Shireman, 1996). These ponds tend to be smaller than food production ponds. Ponds average 7.6 × 22.8 m with a maximum depth of 1.8 m (Watson and Shireman, 1996). This differs from food production aquaculture as a whole in that the marine coastal environment is not utilized, primarily because few marine ornamentals are produced in large quantities. Invertebrates, in particular sponges and clams, are the primary marine ornamental species. Although a considerable proportion of production tends to resemble semi-intensive food production aquaculture, stocking densities of some ornamental species can match that of food species. While livebearing adults are stocked in ponds at 2.6 fish/m^3 (FL Seafood, 2000), tiger barb fry will be stocked as dense as 10,000 fish/m^3 (Tamaru et al, 1997). Tank culture of marine clownfish (*Amphiprion* spp.) tends to vary between 700 and 3800/m^3 (Hoff, 1996). In comparison to larval stages of food-fish, Atlantic cod (*Gadus morhua*) are stocked at 55,000 fish/m^3, barramundi (*Lates calcarifer*) at 30,000 fish/m^3, and European sea bass (*Dicentrarchus labrax*) at 144,000 fish/m^3 (Tucker, 1998). However, these are maxima, and represent species that are commercially important. The lower range of stocking densities for other food species includes yellowfin tuna (*Thunnus albacares*) stocked at 20 fish/m^3, and Nassau grouper (*Epinephelus striatus*) stocked at 300 fish/m^3 (Tucker, 1998).

Ornamental-fish aquaculture has many other similarities to food-fish aquaculture. Food production aquaculture is often criticized as having a goal of creating a high-value end product that does not significantly add to overall global food supplies (Naylor et al., 2000). Similarly, the ornamental fish industry produces a luxury item that the industry targets to a select group of end users. The US market demands 60% of ornamental fish production, while the remainder is consumed primarily by markets in Western Europe, Japan, Taiwan, and Australia (Walton, 1994). In the US, only 10% of households with pets have freshwater fish, while 0.8% have saltwater fish. This utilization by a small percent of US consumers classifies ornamental fish as a luxury item such as boats or high-end electronics. However, as opposed to other luxury items but similar to aquaculture production in general, the ornamental fish industry can have, under the proper developmental scenario, a positive impact on the global economy, particularly in less developed areas. Many of the fish in this industry originate in areas that are currently economically depressed (e.g. South America, Sri Lanka, Pacific islands, Brazil).

4. Benefits of culturing ornamental species

4.1. Economic support

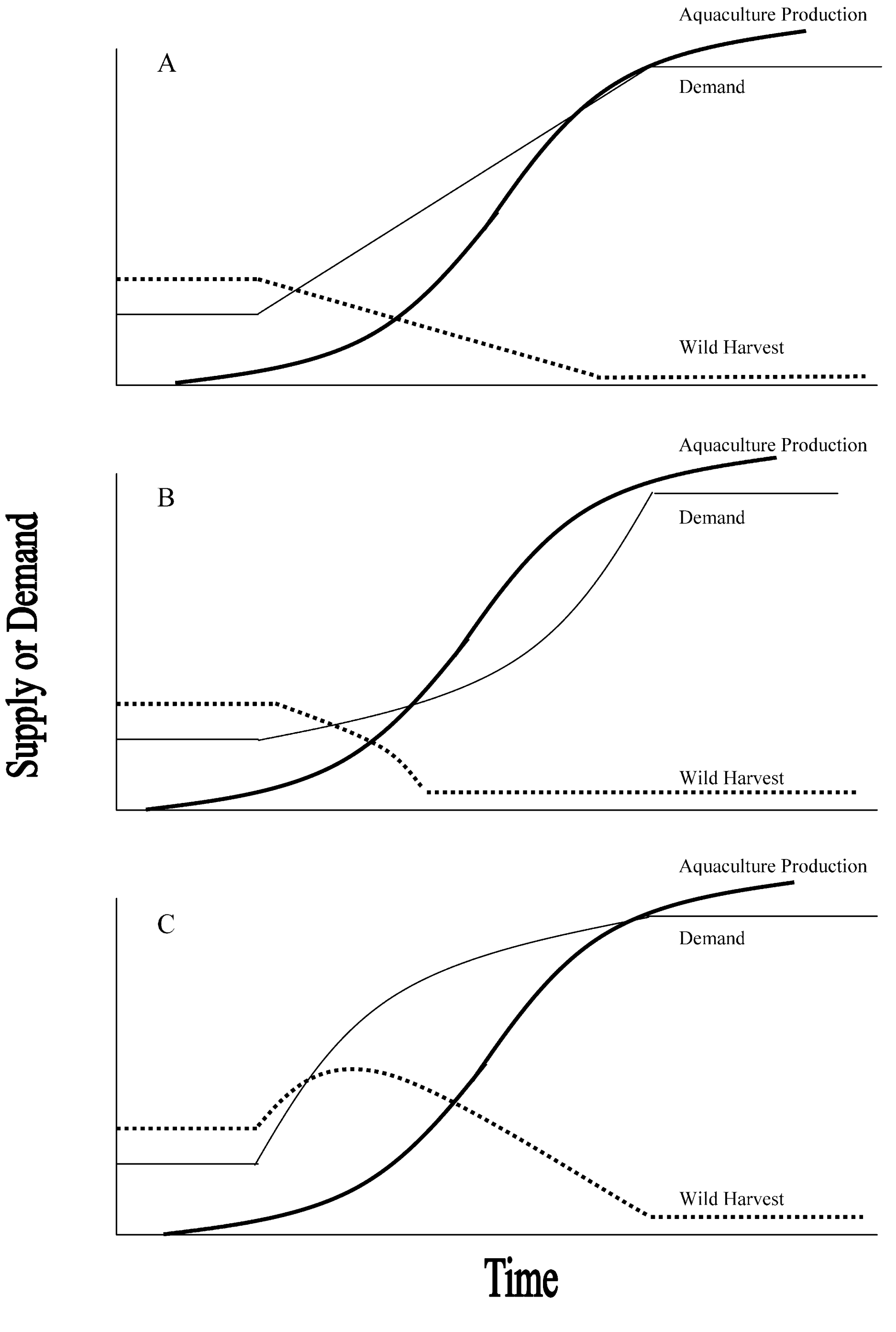
The importance of the fish hobbyist industry cannot be denied. The total ornamental fish industry (including dry goods) is valued at approximately US$15 billion (Bartley, 2000). The ornamental industry supports developing countries, as 60% of exports come from such areas (Bartley, 2000). In Amazonas, Brazil, this industry accounts for 60% of the local economy (Chao and Prang, 1997; Dowd and Tlusty, 2000), while collectors in the Philippines have few employment alternatives (Baquero, 2001). However, these economic benefits currently are derived from the capture industry. Aquacultural operations tend to be focused in developed areas where there is sufficient capital investment required for the high cost of developing the necessary infrastructure. Aquacultural development of the ornamental sector has been most prevalent in Florida (200 farms) and Singapore (over 100 farms, L. Chuan, pers. comm.). For the economic benefits of aquaculture production for the aquarium industry to continue to reach impoverished and coastal areas, a conscious effort to develop it in these areas is necessary.

4.2. Lessened impacts on wild stocks

As with the food production sector, captive culture can dramatically decrease the need to collect wild stocks (Fig. 1A). The decrease in wild harvests depends on the market demand being fulfilled by aquacultural production. The quicker aquacultural production develops compared to the market demand, the quicker the decrease in reliance on wild harvests (see Fig. 1B). Examples of aquacultural production replacing wild harvests include the golden dragon fish (*Scleropagus formosas*), which is endangered (CITES-1, ICUN red list EN A1cd + 2cd, WCMC, 2000). Wild harvests would further endanger the resource and inhibit support of the pet trade. Yet, golden dragon fish are being successfully raised for sale to the pet industry at a licensed facility (Bartley, 2000). Another example is bala sharks (*Balantiocheilos melanopterus*) which were overfished to the point of extinction in their native Sumatra (Ng and Tan, 1997). However, culture of this species has advanced to the point where a majority of individuals entering the aquarium trade originate from culture operations (Ng and Tan, 1997). Thus, in these cases, captive propagation has reduced or eliminated the need to capture wild fish.

A species does not have to be completely cultured in captivity to benefit from the aquacultural production. As mentioned previously, aquacultural production of juveniles, and subsequent releases to the wild (enhancement or ranching) can benefit collectors as well as decreasing the impact on the wild species. While most enhancement focuses on species important for food or sport, there are a few examples more pertinent to the aquarium trade. "Live rock" is currently being cultured (Baquero, 1999; Bruckner, 2000; Watson, 2000), and many conch species (*Trochus* spp.) are produced in hatcheries, then seeded out to reefs (Watson, 2000). Aquacultural production also can be beneficial when a species is difficult to catch or highly dispersed (Watson, 2000). There are other benefits that the aquacultural industry can provide to wild collectors without developing full-scale aquaculture production. Along with captive culture, aquaculturists have developed the capacity for the safe and efficient handling and transportation of live animals since this is a large problem in the ornamental fish trade (Chapman et al., 1997, 1998; Waichman et al., 2001). Aquaculturists can work with collectors to assure that the fish that are collected

Fig. 1. The relationship between aquacultural supply (bold line), demand for a species (thin line) and its impact on the wild harvest (dashed line). In this case, demand is met by aquaculture and wild harvest supply, and for ease of presentation, the supply is slightly greater than the demand. Generally, any increase in aquacultural supply leads to a decrease in the harvest of wild species (A). If the demand function is concave up (B), then the lag in increased demand allows the aquacultural supply to meet a majority of the demand, and the wild harvest quickly declines. However, if the demand function is concave down (C), then the initial surge in demand will outpace aquacultural supply, and the wild harvests will increase before decreasing.



Aquaculture Production
A
Demand
Wild Harvest
Aquaculture Production
B
Demand
Wild Harvest
Aquaculture Production
C
Demand
Wild Harvest
Supply or Demand
Time

from the wild arrive in retail markets in as high a quality as possible with as few moralities as possible (Macmillan, 2000a,b).

4.3. Efficient production

A production facility located close to an international airport can do much to decrease the cost of production. Not only are transport costs decreased, but losses during shipping are also reduced given a shorter transit time. The production of fish in an aquacultural setting is more predictable, in terms of supply and price (Watson, 2000), and thus, the product is more attractive to buyers. In addition, many aquacultural produced fish are more suited to continued holding in captivity and are of higher quality compared to wild caught fish (Stayman, 1999). Aquacultural production can be particularly efficient compared to a wild harvest for fish that are difficult to catch. Dwarf cichlids (*Apistogramma* spp.) are highly dispersed in their natural habitat, and thus, would benefit from aquaculture production provided the demand for them increases (Watson, 2000).

Culture operations are often family units (MacMillan, 2000a,b), or employ under-represented genders in the work force. Coral culture in the Solomon Islands is typically the charge of women (Bartley, 2000). This represents one of the few economic opportunities for women in this area.

4.4. Species conservation

Aquaculture provides a scenario in which species can be completely cultured in captivity. This is the basis for species survival programs. There are currently 28 species of *Haplochromine* cichlids that are being captively managed through the Species Survival Program of the American Zoological Association (AZA, 1996). Although much of the cichlid effort is of low intensity, it nonetheless represents basic aquacultural production. The golden arrowana, bala shark, pygmy loach (*Botia sidthimunki*), and tiger barb (*Puntius tetrazona*) are all species that have been conserved via aquacultural production (Ng and Tan, 1997). In addition to the sale of fish to hobbyists, fish are also being reintroduced to habitats in which they have been eliminated. Similar cases include barbs from Sri Lanka (*Barbus bandula, B. cumingi, B. nigrofasciatus* and *B. titteya*, Dawes, 2001), and sea turtles and alligators (Landau, 1992). In 1973, the American alligator (*Alligator mississippiensis*) was put on the endangered species list, but was reclassified to threatened in 1978 with assistance from captive rearing programs (Landau, 1992).

4.5. Research

One of the primary benefits of aquaculture development is that the species' biology is thoroughly investigated. This often leads to new methods of culture, e.g. breeding, larval rearing, and feeding, that can then be transferred to other species (Dhert et al., 1997). Currently, only a few captively cultured marine fish are commercially available; these include clownfish, gobies, and dottybacks (Schiemer, 2001; Tucker, 1998). However, more species, many of which could not be successfully reared a decade ago, are on the verge of being commercialized, including basslets, comets, jawfishes, blennies and seahorses (Tucker, 1998). One of the difficulties of captively breeding many marine fish is that their larvae are small and they need small, live foods for first feeding. Thus, determining new live foods is one area where much progress is being made, and is a primary reason for the ability to culture new species. In addition, one last benefit is that information on the general biology of species can further assist wildlife biologists in the management of the species (Nicosia and Lavalli, 1999).

4.6. Novel strains

One additional benefit of captive culture of ornamental fish includes the production of strains that are popular in the hobby, but do not occur in the wild. These include "domesticated" strains as well as hybrid strains. Two examples of the numerous varieties that exist for a species include angelfish (*Pterophyllum scalare*) and bettas (*Betta splendens*). The wild-type coloration of angelfish is silver, yet a minimum of 30 color and finnage varieties can be produced easily (Swann, 1993). Wild angelfish are currently of little commercial demand (L. Chao, U. Amazonas, pers. comm.). Bettas are domesticated to the point that they little resemble wild types, there are 17 color varieties, and 8 finnage types (Bettatalk, 2000), with 40 classes being recognized by the International Betta Congress (IBC, 2000). Such strains, being developed in captive culture, would never be available through wild harvests.

5. Risks

There appear to be fewer risks associated with the culture of ornamental species than to food-fish aquaculture. This is primarily because ornamental operations do not operate in coastal, publicly owned waterways. Thus, while pond nutrification and addition of antibiotics and other chemicals to the ecosystem are an issue, pond aquaculture can be managed in ways that limit the discharge of wastes into public waterways. The ponds are generally flushed and dried between stockings with the waste being collected (Ekkwill, 2000), minimizing the accumulation of waste material. In contrast, there are a few examples of where intensive production of food fish aquaculture in marine environments have contributed to the degradation of the surrounding environment (Gowen and Bradbury, 1987; Laurén-Määttä et al., 1991; Silvert, 1992; Krost et al., 1994). Because of these few examples, even though other studies demonstrate few if any impacts (Wu, 1995; Ervik et al., 1997; Tlusty et al., 2000), aquaculture is generally viewed by the public as being detrimental to the integrity of the environment. However, there are a few risks that are common to both ornamental and food-fish aquaculture.

5.1. Shifting of economic base

As alluded to previously, aquacultural production of ornamental fish can remove a resource base from a developing area to developed countries with the infrastructure to support aquaculture operations. In general, efficient aquacultural producers tend to be larger organizations centered near major airports. This trend in production favors development away from rural areas into developed centers. Along with this shift comes a long-term loss of control over biological property. For example, a majority of Malawi cichlids are produced in Florida and Singapore, while the neon tetra is primarily supplied from Hong Kong (Watson, 2000). While the 1992 Convention on Biological Diversity should assure that some economic benefits return to the country of origin, this treaty has not achieved its intended success to date (Watson, 2000). In addition, the economic benefits accrued from an aquacultural operation would most likely be shifted elsewhere, and not to those individuals originally involved in the harvest of the species (Project Seahorse, 1999). Aquaculture is seen as a threat by collectors in developing nations, and 75% of marine collectors from Sri Lanka do not support aquacultural initiatives (Watson, 2000). Any aquacultural program designed to replace a capture fishery that does not incorporate involvement of the fishers, particularly in economically depressed areas, is unlikely to be supported, and will have little conservation benefits (Project Seahorse, 1999).

5.2. Impacts to wild stocks

While decreased impacts to wild stocks have been hypothesized for food production aquaculture, and can occur in ornamental production (see above), the decreased impacts are not as dramatic as theorized. In the food production sector, wild harvests have not declined even with increasing aquaculture production (Naylor et al., 2000). In the ornamental fish industry, breeders (particularly those of cichlids) utilize wild stock every two to three generations (Dawes, 2001), thus there is a continued dependence on wild stocks. One of the main arguments against aquacultural production of seahorses (*Hippocampus* spp.) is that captive culture relies heavily on repeated removals of wild animals and thus, provides no net benefit to wild seahorse populations (Project Seahorse, 1999).

When a species is "discovered" by the aquarium trade, the sudden interest often leads to a decline in wild populations. The same could happen if initial aquaculture attempts lead to an increase in popularity. In this case, the increased demand can outpace the increased aquaculture supply (Fig. 1C). This leads to a case where wild harvests have to be initially increased to meet the demand. These increased harvests remain until the aquacultural production increased to meet the demand (Fig. 1C). The bala shark was introduced into the trade in the late 1970s, became popular, and was subsequently overfished to the point of extinction in Sumatra (Ng and Tan, 1997). Now it is sufficiently produced in aquacultural operations without further reliance on wild collections. One difficulty with this scenario is that if the aquacultural operations are not successful, then this production may cease which would leave a legacy of increased demand for a wild-caught product.

A second way aquaculture may impact wild stocks is through the release of non-indigenous species into the ecosystem. Currently, 185 species of non-indigenous fish have been found in US waters, and 75 species have established breeding populations (USGS, 2000a). Approximately 65% of these are escapees from production facilities (Courtenay and Stauffer, 1990), with many others being releases by hobbyists. While many introduced species compete with their native ecological equivalents, some introduced species are predatory, have the potential to disrupt food webs, and compete with native flora for food (USGS, 2000b). Although some of the risk is minimized by tropical fish being released in temperate climates, the establishment of breeding populations of tropical fish in temperate areas requires further examination of this potential.

5.3. Impacts to predators

Generally, aquacultural production of ornamentals occurs where predators cannot access the stock. The rearing of larvae occurs in hatcheries, while outdoor ponds are often covered by plastic in the winter, and with 5 cm predator netting in the summer (Ekkwill, 2000). Birds are the most common type of predator observed around freshwater farm ponds (Stickley, 1990). In Florida, fish in netted ponds experienced lower mortality rates compared to those in unnetted ponds 11.1% vs. 37.6%, respectively, (M. Avery, USDA/APHIS/WS National Wildlife Research Center, Gainesville, FL, pers. comm.). Efforts are made to limit the number of predators killed around aquaculture operations, and Florida will not issue depredation permits for birds (M. Avery, pers. comm.). There also are risks to production in semi-enclosed marine environments. Young giant clams are vulnerable to attack by fish, octopus and snails and must be protected by cages. These can be bamboo or plastic, and are placed over the clams on the ocean floor.

5.4. Use of fish meal

There is a concern in food-production aquaculture that fish are being caught to feed other fish, and that there is little positive benefit from this scenario (Naylor et al., 2000). However, much of the fish caught for fishmeal is not preferred for human consumption, and includes capelin, jack mackerel, and menhaden (Fossbakk, 2000). Many ornamental flake fish foods list fishmeal as their primary ingredient, yet it is difficult to assess the total amount of fishmeal used in ornamental aquaculture. Ornamental fish aquacultural production statistics generally focus on the value rather than the weight of product generated. The greater price per unit weight of ornamentals skews any comparison between value and weight. Thus, even though ornamental fish aquaculture accounts for 7% of the US industry, it cannot be assumed that this sector uses 7% of the fishmeal used for the production of food species. The issue is conversion of fish protein (although likely to be unpreferred for human consumption) into non-consumable luxury items. However, the economic benefits of ornamental aquaculture and the associated hobbyist industry are likely to offset the amount of fish converted to fishmeal for use in these operations.

6. Captive culture for the aquarium trade

The above analysis of risks and benefits can be used to develop criteria under which captive culture of animals for the aquarium trade should be continued, and where it should be avoided (Table 2). The first benefit of ornamental aquaculture focuses on species

Table 2
The appropriate and inappropriate cases of aquaculture production of ornamental species

Appropriate	Example
Demand cannot be met by wild harvest	dwarf cichlids (*Apistogramma* spp.)
Rare in wild	Golden dragon fish (*Scleropagus formosas*)
Rare in trade (abundant in wild)	cichlid (*Hoplarchus psittacus)*
Destructive harvest methods	hard corals
Benefit collectors and wild populations	Conchs (*Trochus* spp.), hard corals
"domesticated" strains	guppies (*Poecilia reticulata*), goldfish (Carassiu auratus), bettas (*Betta splendens*), angelfish (*Pterophyllum scalare*)
Inappropriate	**Example**
Wild harvest maintains habitat	Cardinal tetra (*Paracheirodon axelrodi*)
Maintains cultural traditions	Cardinal tetra (*Par. axelrodi*)
Removal of economic benefit from depressed/developing area	Sri Lanka and Brazilian ornamental fishery
Propagation hastens decline of wild population	seahorses (*Hippocampus* spp.)

conservation, and production of species that are difficult to obtain from the wild. This includes animals that are rare in the wild, animals that are abundant in the wild but rare in the trade, as well as cases where demand cannot be met by a wild harvest. The previously discussed golden dragon fish exemplifies the first case. It is rare in the wild, and a captive breeding effort was initiated to the extent that now, second generation captive-bred animals can be sold in the aquarium trade. The second case, abundant in the wild but rare in the aquarium trade, is illustrated by the Brazilian cichlid *Hoplarchus psittacus*. This fish is restricted for export from Brazil, even though it is abundant throughout its range (S. Dowd, New England Aquarium, pers. comm.). Thus, animals that do exist in the aquarium trade are valuable, and progeny reared in captivity can be sold for as much as US$3.15/cm. Finally, for some animals, their demand cannot be met by a wild harvest. Dwarf cichlids (*Apistogramma* spp.) are highly dispersed and difficult to catch, and thus, make a likely candidate for culture (Watson, 2000) should the demand become great enough.

The second benefit of ornamental aquaculture is minimizing environmental harm or conversely, maximizing environmental benefits. Hard corals are often harvested via destructive methods (Baquero, 1999, Bruckner, 2000). A non-destructive method to harvest corals is to plant artificial substrate on or adjacent to reefs where it is then colonized by the coral (Bruckner, 2000). Harvesting is simply a matter of picking up these artificial substrates (Baquero, 1999). Thus, an environmentally destructive harvest method was molded into a non-destructive ranching method. Similar ranching efforts involve conch (*Trochus* spp.), and giant clams (*Tridacnidae*) (Stayman, 1999). Environmental benefits may also be indirect, or be conferred to non-target species. The collection of anemones not only removes the target species from the wild, but removes habitat for non-target species such as clownfish (C. Watson Tropical Aquaculture Laboratory, Univ. FL.

pers. comm.). Therefore, aquaculture production of anemones will serve two benefits: directly to the anemones themselves, and indirectly to the animals that use the anemones as habitat.

The final benefit of ornamental aquaculture is that many color varieties and body types can be produced for increased marketing and variety. The 2000 Goldfish Society of American Convention had 18 classes of goldfish (*Carassius auratus*) in five groups (GFSA, 2000), and guppies (*Poecilia reticulata*) are divided into 51 finnage/color classes (IFGA, 1999). The breeding of these varieties serves to have hobbyists participate in more advanced aspects of the hobby.

7. Inappropriate culture of ornamentals

Even with the numerous benefits provided by aquacultural production of species for the aquarium trade, there are a few key cases where a switch to aquacultural production should be made with great caution, or avoided all together (Table 2). The main area in which captive cultivation should be avoided is when the wild harvest maintains habitat and a cultural or economic benefit that would disappear if collecting was stopped. In Brazil, the wild harvest of ornamental fish, and particularly the cardinal tetra (*Paracheirodon axelrodi*) which accounts for 80% of the fish exports (Chao and Prada-Pedreros, 1995; Chao, 1998), provides a large economic benefit to the inhabitants of the Rio Negro basin (Prang, 1996; Dowd and Tlusty, 2000), including benefits to children (Axelrod, in press; Licoski, 1997). This economic benefit is preventing the development of agriculture and mining that would otherwise destroy the flooded forest ecosystem (Dowd and Tlusty, 2000). This industry also prevents outmigration to urban centers by people seeking employment opportunities (Chao and Prang, 1997). Retaining younger people in rural forest villages also serves to keep cultural traditions alive. Thus, the economic development of the ornamental fishery is mutualistic to the preservation of this ecosystem. Captively culturing cardinal tetras, particularly anywhere outside the country (as are neon tetras, *P. innesi*, in Florida), would decimate the economy of this area, as well as open up the flooded forest to environmentally destructive industries (Chao et al., 2001). Although efforts are being made to determine culture methods for the cardinal tetra (Burton et al., 1998), the entire suite of social, economic, and ecological ramifications of such actions need to be fully explored.

Other areas that support ornamental harvests demonstrate similar economic and cultural benefits. The Sri Lankan ornamental fishery represents 8% of the volume of exported fish, but accounts for 70% of its value (Bartley, 2000). Given the number of people this industry supports, few fishers are willing to support aquacultural ventures (Watson, 2000).

The final reason that aquaculture production of ornamentals may be inappropriate is the situation where the production of animals accelerates a decline in the wild population. This scenario has occurred in the hobbyist industry, specifically to the Banggai cardinalfish (*Pterapogon kauderni*). This species was originally discovered in the 1930s, and became popular in the aquarium trade in 1995 (Flying Fish Express, 2001). Since then, they have become imperiled for a variety of reasons, one being the collecting pressure for the aquarium trade (Souza, 2001). They are currently being captively cultured, but this is adding to their popularity, and not replacing the reliance on wild collections (the scenario of Fig. 1C).

While a gain in popularity could occur for a cultured species, another route to the decline in wild stocks via aquacultural production is if broodstock are difficult to maintain. If this is the case, then production would rely on the repeated collections of wild animals. The repeated collections for a culture industry in this case may actually contribute to the demise of the wild populations. This is the reason behind Project Seahorse (1999) urging against aquaculture production of seahorses.

In summary, the aquacultural production of ornamental fish has resulted in many benefits while few risks have been realized. However, some of the risks have wide reaching environmental and societal consequences. Hence, it is important that the industry conduct a thorough risk-benefit analysis for each new species it proposes to produce in captivity to assure that immediate benefits do not result in future risks.

Acknowledgements

I greatly appreciate the efforts of D. Bartley, G.A.E. Gall, and J. Goldstein for comments on a draft of this manuscript.

References

Anonymous, 2000. Salmon growers aid conservation project. The Fredericton Daily Gleaner, 5 May 2000.

Axelrod, H.R., in press. Discovery of the Cardinal Tetra and Beyond. In: Chao, N.L., Petry, P., Sonneschein, L., Tlusty, M.F. (Eds.), Conservation and Management of Aquatic Resources of the Rio Negro Basin, Amazonia, Brazil. Proceedings of an international workshop on Amazon River biodiversity. Universidade do Amazonas Press, Manaus, Brazil.

AZA, 1996. Cichlids 96 Report. http://www.aza.org/programs/ssp/ssp.cfm. 1 Jan 1996.

Baquero, J., 1999. Marine ornamentals trade: quality and sustainability for the Pacific region. South Pacific Forum Secretariat, Suva, Fiji, and the Marine Aquarium Council. http://www.aquariumcouncil.org/docs/Final%20Marine%20Ornamentals%20Rpt-ver%20June%204.htm., 50 pp.

Baquero, J., 2001. The trade of ornamental fish from the Philippines. In: Chao, N.L., Petry, P., Prang, G., Sonneschein, L., Tlusty, M.F. (Eds.), Conservation and Management of Ornamental Fish Resources of the Rio Negro Basin, Amazonia, Brazil — Project Piaba. Editora da Universidade do Amazonas, Manaus, Brazil, pp. 75–82.

Bartley, D.M., 1999. Marine ranching: a global perspective. In: Howell, B.R., Moksness, E., Svasand, T. (Eds.), Stock Enhancement and Sea Ranching. Fishing News Books, Oxford, pp. 79–90.

Bartley, D.M., 2000. Responsible ornamental fisheries. FAO Aquat. Newsl. 24, 10–14.

Bartley, D., Casal, C.V., 1998. Impacts of introduction on the conservation and sustainable use of aquatic biodiversity. FAO Aquacult. Newsl. 20, 15–19.

Bettatalk, 2000. Betta Finnage. www.bettatalk.com/betta_finnage.htm. 26 November 2000.

Bruckner, A.W., 2000. New threat to coral reefs: trade in coral organisms. Issues in Science and Technology online. Fall 2000. www.nap.edu/issues/17.1 /bruckner.htm. 20 November 2000.

Burton, S., Kaiser, H., Hecht, T., 1998. The potential of Artemia-mediated delivery of a gonadotropin-releasing hormone analogue to induce ovulation in the cardinal tetra (*Paracheirodon axelrodi*). Aquarium Sci. Conserv. 2, 89–92.

Chao, N.L., 1998. A draft list of Brazilian freshwater fishes for the hobby—a proposal to IBAMA. Ornamental Fish Int. J. 23, 11–19.

Chao, N.L., Prada-Pedreros, E.S., 1995. O cardinal tetra, Paracheirodon axelrodi, e diversidade dos peixes ornamentais do Rio Negro, Amazonas. Anais do VII Congresso Brasileiro de Engenharia de Pesca, Santos-SP, 22 a 26 de julho de 1991. Associação dos Engenheiros de pesca de Pernambuco, Recife, pp. 35–51, 1994.

Chao, N.L., Prang, G., 1997. Project Piaba — towards a sustainable ornamental fishery in the Amazon. Aquarium Sci. Conserv. 1, 105–111.

Chao, N.L., Dowd, S., Tlusty, M.F., 2001. Project Piaba: buy a fish , save a tree. Am. Zool. Assoc. Communique 14, 16 January.

Chapman, F.A., Fitz-Coy, S.A., Thunberg, E.M., Adams, C.M., 1997. United States trade in ornamental fish. J. World Aquacult. Soc. 28, 1–10.

Chapman, F.A., Colle, D.E., Rottmann, R.W., Shireman, J.V., 1998. Controlled spawning of the neon tetra. Progr. Fish Cult. 60, 32–37.

Courtenay, W.R., Stauffer, J.R., 1990. The introduced fish problem and the aquarium fish industry. J. World Aquacult. Soc. 21, 145–159.

Dawes, J., 1998. International experience in ornamental marine species management. Part 1: perspectives. Ornamental Fish Int. J., 26, February 1999. http://www.ornamental-fish-int.org/marinespecies1.htm.

Dawes, J., 2001. International aquatic industry perspectives on ornamental fish conservation. In: Chao, N.L., Petry, P., Prang, G., Sonneschein, L., Tlusty, M.F. (Eds.), Conservation and Management of Ornamental Fish Resources of the Rio Negro Basin, Amazonia, Brazil — Project Piaba. Editora da Universidade do Amazonas, Manaus, Brazil, pp. 109–124.

Dhert, P., Lim, L.C., Candreva, P., Van Duffel, H., Sorgeloos, P., 1997. Possible applications of modern fish larviculture technology to ornamental fish production. Aquarium Sci. Conserv. 1, 119–128.

Dowd, S., Tlusty, M.F., 2000. Project Piaba—working toward a sustainable natural resource in Amazon fresh-water fisheries. Endangered Species Update 17, 88–90, Univ. MI. School Natural Resources.

Edwards, P., 1997. Sustainable food production through aquaculture. Aquacult. Asia 2, 4–7.

Ekkwill, 2000. More About EkkWill Waterlife Resources. www.ekkwill.com. 15 October 2000.

Ervik, A., Hansen, P.K., Aure, J., Stigebrandt, A., Johannessen, P., Jahnsen, T., 1997. Regulating the local environmental impact of intensive marine fish farming: I. The concept of the MOM system (Modelling–Ongrowing fish farms–Monitoring). Aquaculture 158, 85–94.

Florida Agriculture Statistical Service, 1999. Aquaculture. www.nass.usda.gov/fl. June 2000.

Florida Seafood, 2000. Tropical fish farming. www.fl-seafood.com/newpages/index.htm. 1 October 2000.

Flying Fish Express, 2001. Banggai Cardinalfish. http://ffexpress.com/fish/misc/banggai.htm. 26 January 2001.

Fossbakk, T., 2000. Worldwatch Institute—misled or misleading? Fish information and Services, www.fis.com/aquaculture/. 3 November 2000.

GFSA, 2000. Virtual Convention. http://www.goldfishsociety.org/virtualconvention.html. 6 Dec 2000.

Goldburg, R., Trippet, T., 1997. Murky Waters: Environmental Effects of Aquaculture in the US. Environmental Defense Fund, 198 pp.

Gowen, R.J., Bradbury, N.B., 1987. The ecological impact of salmonid farming in coastal waters: a review. Oceanogr. Mar. Biol. Ann. Rev. 25, 563–575.

HBOI, 2000. Marine ornamental production. www.hboi.edu/aquaculture/marine.html. 1 October 2000.

Hoff, F.H., 1996. Conditioning, Spawning and Rearing of Fish with Emphasis on Marine Clownfish. Aquaculture Consultants, Dade City, FL, 212 pp.

Hutchinson, P. (Ed.), 1997. Interactions between salmon culture and wild stocks of Atlantic salmon: the scientific and management issues. ICES Mar. Sci. Symp. 205, 263 pp.

IFGA, 1999. Recognized IFGA Show Classes. http://www.guppys.com. 12 June 1999.

International Betta Congress, 2000. 2000-2001 International class standings after 3 shows. www.starpoint.net/~bettas. 28 October 2000.

JSA, 1999. U.S. private aquaculture production of 1985–1997. Ag,ansc.purdue.edu/aquanic/jsa/aquaprod.htm. February 1999.

Kautsky, N., Berg, H., Folke, C., Larsson, J., Troell, M., 1997. Ecological footprint for assessment of resource use and development limitations in shrimp and tilapia aquaculture. Aquacult. Res. 28, 753–766.

Krost, P., Chrzan, T., Schomann, H., Rosenthal, H., 1994. Effects of a floating fish farm in Kiel Fjord on the sediment. J. Appl. Ichthyol. 10, 353–361.

Landau, M., 1992. Introduction to Aquaculture. Wiley, New York, 440 pp.

Laurén-Määttä, C., Granlid, M., Henriksson, S., Koivisto, V., 1991. Effects of fish farming on the macrobenthos of different bottom types. In: Mäkinen, T. (Ed.), Marine Aquaculture and Environment. Nordic Council of Ministers, Copenhagen, pp. 57–84.

Licoski, J.F., 1997. The children of Project Piaba. Trop. Fish Hobbyist 45, 86–92.

Macmillan, L., 2000a. Down on the Fish Farm. Seabits, New England Aquarium Monthly e-mail Newsletter, www.neaq.org., Vol. 4, Issue 11, November 2000.

MacMillan, S.M., 2000b. Starting a successful commercial sponge aquaculture farmCent. Trop. Subtrop. Aquacult. Publ. no. 120, 22 pp.

Munford, J.G., Baxter, J.M., 1991. Conservation and aquaculture. In: De Pauw, N., Joyce, J. (Eds.), Aquaculture and the Environment. Eur. Aquacult. Soc. Spec. Publ., vol. 16, pp. 279–298.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, H., Mooney, H., Troell, M., 2000. Effect of aquaculture on world fish supplies. Nature 405, 1017–1024.

New, M., 1996. Sustainable global aquaculture. World Aquacult. 27, 4–6.

Newell, R.I.E., 1988. Ecological changes in Chesapeake Bay: are they the result of overharvesting the American oyster, *Crassostrea virginica*? Understanding the Estuary: Advances in Chesapeake Bay Research. Proceedings of a Conference. Publication no. 29, Chesapeake Research Consortium, Baltimore, MD, pp. 536–546.

Ng, P.K.L., Tan, H.H., 1997. Freshwater fishes of Southeast Asia: potential for the aquarium fish trade and conservation issues. Aquarium Sci. Conserv. 1, 79–90.

Nicosia, F., Lavalli, K., 1999. Homarid lobster hatcheries: their history and role in research, management, and aquaculture. Mar. Fish. Rev. 61, 1–57.

Olsen, J.H.T., 1996. Developing sustainable aquaculture. World Aquacult. 27, 16–17.

Pillay, T.V.R., 1996. Aquaculture and the Environment. Fishing News Books, Oxford, 189 pp.

Prang, G., 1996. Pursuing the sustainable development of wild caught ornamental fishes in the middle Rio Negro, Amazonas, Brazil. Aquat. Survival 5, 6–8.

Project Seahorse, 1999. Seahorse aquaculture: a position statement from Project Seahorse. www.seahorse.mcgill.ca/position.htm. Seahorse aquaculture. 15 September 2000.

Raa, J., Liltved, H., 1991. An assessment of the compatibility between fish farming and the Norwegian coastal environment. In: De Pauw, N., Joyce, J. (Eds.), Aquaculture and the Environment. Eur. Aquacult. Soc. Spec. Publ., vol. 16, pp. 51–59.

Rice, M.A., Valliere, A., Gibson, M., Ganz, A., 2000. Ecological significance of the Providence River quahogs: population filtration. J. Shellfish Res. 19, 580.

Schiemer, G., March 2001. Captive-bred marine fish. Aquar. Fish. Mag., 41–45.

Silvert, W., 1992. Assessing environmental impacts of finfish aquaculture in marine waters. Aquaculture 107, 67–79.

Souza, M., 2001. AZA's conservation endowment fund: supporting field conservation. Am. Zool. Assoc. Communique, January 8–9, 50.

Stayman, A.P., 1999. A policy maker's viewpoint: the marine species in your tank—where do they come from? Trop. Fish Hobbyist 47, 30–32, 34.

Stickley, A.R., 1990. Avian predators on southern aquaculture. Southern Regional Aquaculture Center. Publ. no. 400, 8 pp.

Swann, L., 1993. Reproduction of Angelfish (*Pterphyllum scalare*). Illinois–Indiana Sea Grant Program Fact Sheet. Publication AS-489, 6 pp.

Tacon, A.G.J., 1995. Aquaculture feeds and feeding in the next millennium: major challenges and issues. First electronic conference on Tropical feeds and feeding systems. www.fao.org/WAICENT/FAOINFO/AGRICULT/AGA/AGAP/FRG/ECONF95/HTML/TACON.HTM. 31 October 2000.

Tamaru, C.S., Cole, B., Bailey, R., Brown, C., 1997. A manual for commercial production of the tiger barb, *Capoeta tetrazona*, a temporary paired tank spawner. Center for Tropical and Subtropical Aquaculture. Publ. no. 129, 50 pp.

Tay, S.H., 1977. ASEAN meeting of experts on aquaculture and cultivation of ornamental fish in cage-nets in Singapore (a recent development). First ASEAN Meeting of Experts on Aquaculture. Semarang, Indonesia, 31 January to 6 February 1977, pp. 217–220.

Tlusty, M.F., Pepper, V.A., Anderson, M.R., 1999. Environmental monitoring of finfish aquaculture sites in Bay d'Espoir, Newfoundland during the winter of 1997. Can. Tech. Rep. Fish. Aquat. Sci. 2273, Vi + 32 pp.

Tlusty, M.F., Hughes, Clark, J.E., Shaw, J., Pepper, V.A., Anderson, M.R., 2000. Groundtruthing multibeam bathymetric surveys of finfish aquaculture sites in the Bay d'Espoir estuarine fjord, Newfoundland. Mar. Tech. Soc. J. 34, 59–67.

Tucker Jr., J.W., 1998. Marine Fish Culture. Kluwer Academic Press, Norwell, MA, 750 pp.

USGS, 2000a. Problems with the Release of Exotic Fish. http://nas.er.usgs.gov/fishes/dont_rel.htm. 1 October 2000.

USGS, 2000b. USGS Scientists Find New Population of Asian Swamp Eels in South Florida. http://biology.usgs.gov/pr/newsrelease/2000/3-3.html. 1 October 2000.

Waichman, A.V., Pinheiro, M., Marcon, J.L., 2001. Water quality monitoring during the transport of Amazonian ornamental fish. In: Chao, N.L., Petry, P., Prang, G., Sonneschein, L., Tlusty, M.F. (Eds.), Conservation and Management of Ornamental Fish Resources of the Rio Negro Basin, Amazonia, Brazil — Project Piaba. Editora da Universidade do Amazonas, Manaus, Brazil, pp. 279–300.

Wallin, M., 1991. Ecometric analysis of factors regulating eutrophication effects in coastal waters: a case study of marine fish farms. Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science, vol. 353, 44 pp.

Walton, A., 1994. Marketability of a cyanide detection kit for use with the ornamental marine fish trade. Department of Biological Science Report submitted to the Industrial Liaisons Office, Simon Fraser University, 112 pp.

Watson, I., 2000. The Role of the Ornamental Fish Industry in Poverty Alleviation. Natural Resources Institute, Kent, UK, Project No. V0120, 66 pp.

Watson, C.A., Shireman, J.V., 1996. Production of ornamental aquarium fish. Department Fisheries and Aquatic Sciences, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publ. FA-35, 5 pp.

WCMC, 2000. Threatened Animals of the World. www.wcmc.org.uk/data/database/rl_anml_combo.html. 26 October 2000.

Wu, R.S.S., 1995. The environmental impact of marine fish culture: toward a sustainable future. Mar. Poll. Bull. 31, 159–166.